Measuring the Value of Health Improvements from Great Lakes Cleanup

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Abstract

Exposure to pollutants in the Great Lakes Region can have significant effects on human health. Some forms of pollution affect humans directly, through the air we breathe and water we drink. Other forms of pollution affect humans indirectly, for example through consumption of contaminated fish. In this paper we describe methods to measure health benefits in monetary and nonmonetary terms in the context of reductions in pollutants as part of a program to improve the environment in the Great Lakes. The paper is meant to be an introduction to this topic for a general audience interested in the Great Lakes.

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Dallas Burtraw and Alan Krupnick*

INTRODUCTION

Exposure to pollutants can have significant effects on human health. Some forms of pollution affect humans directly, through the air we breathe and water we drink. Other forms of pollution affect humans indirectly, for example through consumption of contaminated fish. Air pollutants appear to cause acute and chronic respiratory and heart ailments, as well as contributing to premature death. Persistent toxic substances, such as PCBs and dioxin-like substances sometimes found in fish, can cause neurobehavioral and developmental problems.

All individuals would agree that decreasing exposure to potentially harmful pollution is beneficial, but there is significant disagreement about how to measure the benefits, and specifically whether to measure benefits in monetary terms or express them in physical terms only. Economists point out that monetary valuation is an appropriate way to measure the strength of individual preferences, and a convenient way to compare very dissimilar benefit categories, and to compare benefits with costs, which are usually already denominated in monetary terms. Others argue that it is demeaning to try to value human health because they feel health (just like the environment) should not be subject to sacrifice or compromise. However, just as in the case of natural resource issues, we face scarce resources and competing priorities for controlling pollution and its effects on health. When tradeoffs are necessary, economics seems particularly well suited to provide some guidance about how this best can be accomplished.

Tradeoffs do not always need to be expressed in monetary terms. One example is when the effectiveness of a policy or course of action is to be measured according to a single criterion, such as the reduction in exposure to a specific pollutant. Then *cost-effectiveness analysis* is appropriate. This approach allows comparisons among alternative courses of action by measuring the improvement that can be achieved in nonmonetary terms per dollar of cost (exposures per dollar). Other things equal, those actions that can deliver the greatest "bang for the buck" should be pursued first.

In other cases one may wish to compare dissimilar improvements, such as a reduction in exposure to air pollution with a reduction in exposure to water pollution, that can be achieved for a specific cost. This type of analysis also can be done in nonmonetary terms, but some means must be found for comparing potentially quite different risks associated with the different types of exposures. One example is triage, practiced in the hospital or the battlefield,

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wherein scarce resources (physician time and emergency room space) are allocated on the basis of expected risks of death and the risk reduction that intervention can bring. Less dramatic tradeoffs involving health but made entirely in nonmonetary terms are an everyday fact of life.

A third type of analysis could involve decisions about the level of expenditures or the level of environmental protection that will be pursued. When the level of the budget is variable, the decision involves a comparison with the cost of increasing the budget. Setting the level of the budget, or alternatively setting the level of protection for the environment or public health, introduces the realm for *benefit-cost analysis,* e.g., the comparison of benefits with costs.

In this paper we describe methods to measure health benefits in monetary and nonmonetary terms in the context of reductions in pollutants as part of a program to improve the environment in the Great Lakes. The paper is meant to be an introduction to this topic for a general audience interested in the Great Lakes. Readers should refer to Freeman (1993) for more in depth treatment of valuation for environmental improvements. Kopp, Krupnick, and Toman (1997) provide a comprehensive treatment of issues in benefit-cost analysis. Johnson et al. (1998) provides a good survey of the toxicological and epidemiological literature relevant to persistent toxic substances affecting the Great Lakes.

PRINCIPLES OF VALUATION

Two ideas are central to valuing changes in human health. First, because a given public policy decision rarely leads to major changes in health status, the data that economists need to estimate values are only for *small changes* in health status, or in the *risk* of a major change in health status. An incident of the flu with its associated symptoms may be thought of as a small change in health status. A one in ten-thousand change in the risk of death is a small change in risk of a major change in health status (given that the baseline risk of death is 80 in ten thousand). Individuals rarely face decisions about major changes in health status, and observed behavior can not provide data on how to value them. But individuals regularly make decisions reflected in their behavior that reveals their willingness to accept health risk, and this provides the data economists need to estimate the value of changes in risk.

Second, the economic notion of value is a measure of how an individual or group would trade-off one thing for another. The notion of a numerical value *per se* does not exist, and there is no meaning to "economic value" outside the context in which tradeoffs have to be made. The data that economists use to assess value comes from the *choices that individuals make* in such contexts. Absent a meaningful choice, there is no meaningful notion of economic value.

These two ideas are important because they help to dispel a common misperception that economics places value on human life (or health). Indeed, an economist is no more capable of assessing the value of a human life than is any other individual, and to suggest that public policy do so is unacceptable in democratic society.

Instead, economists collect and interpret data about how the choices individuals make reflect those individuals' attitudes toward risks. Individuals (and society) regularly make decisions that affect relative health risks. In doing so, we make a choice about the probability of one outcome or another.

For instance, sidewalks always can be constructed to be wider and with curbs cut higher to provide additional margins of safety for pedestrians. Current standards may be deemed acceptable, but they do not entirely eliminate the risk of a runaway automobile striking a pedestrian. By assessing the probability of such an unfortunate event, and considering the cost of changing that probability through wider sidewalks or higher curbs, one can infer the value society (or at least the Department of Public Works) places on avoiding accidents, including accidental death. Similar choices are made by individuals, in deciding the level of risks that are acceptable in various contexts, such as speeding up on a highway to save time. These choices offer data for the consideration of policies to reduce pollution and their effect on health through changes in the incidence of morbidity (disease) and premature mortality (death).

The notion of value that is useful in economic analysis is the individual *willingness-to-pay* for small reductions in risk (or small changes in health status). In technical terms, this measure should reflect the maximum amount of money that could be subtracted from an individual's income while providing for an environmental improvement, such that one is just indifferent between this outcome and the prior situation with more income but without the environmental improvement. Since this is a maximum amount, any environmental improvement that cost the individual less than this amount would actually leave him or her better off. Often it is not possible to identify this perfect measure, and in practice one must cobble together estimates.

TECHNIQUES FOR VALUATION

The techniques for measuring the benefits of improvements in health fall into two general categories. The *stated preference* technique involves asking people questions in surveys to elicit, either directly or indirectly, estimates of the willingness-to-pay for the improvement in question. Examples include contingent valuation methods, which are structured surveys meant to elicit preferences in monetary terms when confronted with a choice, and conjoint analysis, an approach used extensively to elicit preferences for particular combinations of attributes that describe health status and alternatives.

The second category is the *revealed preference* technique. In this case economists collect data about actual behavior either in the marketplace or elsewhere to discern willingness-to-pay for improvements in risk or health status.

When properly applied, the stated or revealed preference analyses are generally acknowledged to produce valid results, but both techniques are subject to limitations. In response to the "constructed" nature of stated preference surveys, respondents might provide inaccurate information due to poorly understood questions or poorly designed questions that invite strategic behavior on the part of those surveyed. Revealed preference techniques, while based on actual consumer behavior, are restricted to the observed market conditions. As a result, they may be of limited value in situations where the conditions to be analyzed differ substantially from current markets. An analysis based on a combination of revealed and stated preference data can draw from the strengths of each of the two methods.

One type of revealed preference data, though at best a weak proxy for willingness-to-pay, is the measure of *cost of illness*. This approach involves accounting for out-of-pocket and in-kind expenses associated with specific health effects. These could include doctor visits, medicine, hospital admissions and lost work days, and information not reflected by consumers' actions, such as charges paid by insurance companies. The approach is inadequate because it fails to account for the discomfort and inconvenience of an illness. Obviously, individuals would be willing to pay in excess of their cost of an illness, sometimes substantially so, in order to avoid the illness altogether. Also, the availability of insurance can affect individuals' actions and the level of care taken to avoid harm to themselves or others, thereby distorting the measure of cost.

The distribution of income also affects this measure of cost since the limitation on the ability to pay imparts a limit on the measure of cost of illness. Typically this aspect of income distribution is addressed by using a measure that represents the average for the population (across all income groups), but when a harm or illness befalls a low-income group disproportionately, the measure of cost of illness will reflect the distribution of income.

Extended to the consideration of premature mortality, a cost of illness approach translates into the measure of *lost earnings.* This old-fashioned approach to valuation relied on a calculation of the present discounted value of future earnings that were lost due to premature mortality. Sometimes this approach has been used as the basis for actual compensation for job-related fatalities, with the result that the death of individuals who differ only in their annual income would lead to different levels of compensation. Consequently, this approach is found to be offensive on both equity and efficiency grounds.

More complete willingness to pay estimates for morbidity and mortality sometimes can be drawn from observed behavior in product markets, the workplace or in other settings. This approach may be called the *averting behavior* approach. In product markets, economists observe individuals making decisions about products with differing safety attributes and different prices. From this data, one can infer willingness to pay for small reductions in risk. Values can be placed on any steps individuals take to avoid some "bad" outcome as a proxy of the willingness-to-pay to avoid that outcome.

For instance, if someone purchases bottled water to reduce the potential for consumption of pollutants in the local water supply, the added costs of their water bill may have some relationship to their willingness-to-pay to avoid the health effect. A problem with this approach concerns separating out the joint effects of a given product. For instance, bottled water may taste better, and some of the full willingness-to-pay may be due to this attribute. Similarly, the purchase of a smoke detector affects multiple risks such as the risk of death, injury and expected losses of property, and its value can not be applied to just one of these.

In the workplace, there are a variety of attributes that distinguish among jobs, one of which is workplace safety. When it is possible to control for all the other distinctions, one can look at differences in workplace safety and differences in wages to calculate the *compensating wage differential* between relatively safer or more dangerous jobs or occupations. This differential reflects the additional wages that are required to entice an average worker to accept additional risk. Under the assumption that individuals are well-informed of such risk differences and are free to chose among employment alternatives (assumptions that often do not hold) then one can infer a willingness to pay to avoid such risks. (See insert box.)

The outcome of a process of valuation typically is an estimate of the willingness-to-pay in monetary terms for a small reduction in risk. The policy analyst can extrapolate from this data to provide an estimate of the value of statistical event as described in the **insert box**.

The Value of a Statistical Life

Often workers have the opportunity to make choices about activities in the workplace or their job classification. Part of that choice may reflect considerations about relative safety risks and the relative wages in different jobs. The *compensating wage differential* is defined as the difference in wage that is sufficient to entice a worker to accept a less desirable job, such as one with a greater risk to worker safety. Economists sometimes rely on this kind of data from occupational choices to calculate the value of statistical life. This technique is referred to as the *hedonic labor market* approach.

Imagine that we observe two occupational categories, and we are able to control statistically for all the non-safety related differences between these jobs to find the difference in wage associated with differences in safety. We find the difference to be $500 per year and to be associated with an increase in the risk of a fatal accident of 1 in 10,000 per year. We can divide the difference in wage by the difference in risk to obtain the implicit value of a statistical life in the following way:

$$\frac{\text{500 dollars}}{\frac{1}{10,000}\text{ statistical risk of death}} = 5 \text{ million dollars per statistical life}$$

Though conceptually simple, this type of calculation has plenty of practical problems when used as a measure of preferences for reducing mortality risks. Workers may not have the economic freedom to choose among occupational alternatives. Further, it is not easy to control for all the differences in occupational categories unrelated to safety that may be contributing to differences in wages. Also, one must account for the risk of injury separately from accounting for the risk of mortality. Other factors can complicate the statistics, including differences in age and sex, and there is evidence that workers sort themselves by a willingness-to-accept risk. If the least risk-averse individuals chose dangerous jobs then there would be a bias in applying the relevant wage differential that would understate the compensating wage differential among the entire population.

COMPARISONS WITHOUT VALUATION

For a variety of reasons a nonmonetary measure of environmental benefits may be preferred in public policy discussions. One reason may be that participants feel it "cheapens" the intrinsic value of health to place a value on it. Another reason may be that monetary values cannot be estimated when one cannot identify or construct meaningful choices that reveal how people view risk tradeoffs in monetary terms. The relation between health risk and monetary values is an abstract and difficult one. Psychologists find that individuals typically have an easier time and provide more replicable answers in making comparisons between more similar objects or concepts. In psychology this is known as the compatibility hypothesis, which suggests that calculation of and consistent judgment about tradeoffs is facilitated when comparing risks or outcomes with similar attributes. Furthermore, values may be more acceptable in the policy context if they are expressed in terms of relative risks rather than in monetary terms.

One technique for doing so is conjoint analysis, which is a stated preference method designed to elicit choices among alternatives without necessarily relating those alternatives to a money value. For example, one study asked individuals who had family members who suffered from chronic lung disease to make choices over living in one of two cities: one with a greater chance of dying in an auto accident, the other with a greater chance of developing chronic bronchitis. The result was a measure of willingness-to-trade-off a risk of a chronic condition for a risk of accidental death. The authors went further by translating these measures to monetary terms by asking for the tradeoff between the risk of chronic bronchitis and the cost of living in the cities (Krupnick and Cropper, 1992). Another ongoing effort is using conjoint analysis to ask individuals to compare and rank episodes of various types of health impairments, in order to analyze attitudes toward disease that can result from exposure to air pollution (Desvousges, 1996).

The comparison of one type of impairment to health with another may seem difficult, at best. However, there is surprising evidence that individuals, at least trained health professionals, from different cultures and different parts of the world have consistent attitudes toward the relative severity of dissimilar diseases. An ongoing study by the World Health Organization (WHO) and the Harvard School of Public Health is exploring attitudes toward disease in attempting to assess priorities for public health expenditures around the world. The study convened focus groups of health professionals from a number of countries. In order to establish a ranking for expenditures of funds for assistance, these groups were asked to deliberate over the severity of diseases. The groups arrived at remarkably similar results even when representing large cultural diversity, suggesting that trained health professionals from different cultures can make consistent decisions over difficult choices about health effects when the choice context is meaningful and well-informed. Whether this consistency would extend to society in general is a matter for future study. In addition, the study focused on ranking public health outcomes as opposed to private risk rankings, which is the more relevant measure for cost-benefit analysis.

The Global Burden of Disease is a study by the Harvard School of Public Health that is attempting a comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020 (Murray and Lopez, 1996). As part of the study, researchers convened focus groups of health professionals and other individuals from around the world to deliberate the relative severity of a wide variety of disabilities. Each participant in the study was asked two questions. One concerned extending life for people in a given health state versus extending life for healthy people, the second concerned giving health back to people in a given health status versus extending life for healthy people. Through a deliberative process the inconsistencies in the answers to these questions were explored, along with the implications of their decisions.

A sample of the resulting weights that were given to different types of disability is reported in the table. These weights reflect a judgement about the relative severity of disabilities on a scale that culminates in a weight of one given to death. This type of measure could be used as an index over many different health outcomes which, when paired with cost information, would permit the conduct of a cost-effectiveness analysis over dissimilar health outcomes. Although few of the indicator conditions in the table reflect conditions directly attributable to the environmental problems we discuss, the table provides evidence that such comparisons can be made in a consistent and replicable fashion. However, this approach still would not permit the aggregation of nonhealth outcomes with health outcomes.

Comparing the Severity of Disabilities

Disability Class	Severity Weights	Indicator Conditions
1	0 - 0.02	weight-for-height less than 2 standard deviations, vitiligo on face
2	0.02 - 0.12	diarrhea, severe sore throat, severe anemia
3	0.12 - 0.24	radius fracture, infertility, erectile dysfunction, arthritis, angina
4	0.24 - 0.36	below knee amputation, deafness
5	0.36 - 0.5	mild mental retardation, Down syndrome, rectovaginal fistula
6	0.5 - 0.7	unipolar depression, blindness, paraplegia
7	0.7 - 1	active psychosis, dementia, severe migraine, quadriplegia

Source: Murray and Lopez, 1996

VALUATION OF POTENTIAL HEALTH EFFECTS OF POLLUTION IN THE GREAT LAKES

The uncertainties implicit in analyzing health risks pose especially difficult challenges for public policy, but much of the difficulty lies outside of economic analysis. In order for economists to estimate the willingness to pay for changes in health risk, individuals need only to have a fairly precise idea of health status alternatives.

However, to relate this willingness to pay for changes in risk (changes in health status) to a willingness to pay for changes in pollution one needs a great deal more information from disciplines other than economics. The identification of risks requires knowledge about:

- changes in emissions,
- how these affect changes in concentrations of pollutants in various environmental media (water, air, soils),
- how these affect changes in exposure, and
- how health status responds to changes in exposure.

With this information in place, one can apply economic estimates of changes in health status to changes upstream in the causal chain relating emissions and health status.

Findings of Health Effects in the Human Population in the Great Lakes Region

In this discussion we review some of the health effects evidence. In some cases this evidence is compelling; in other cases, it is less so.

An issue of particular interest to the Great Lakes region is the health risk associated with consumption of fish that is potentially contaminated with various pollutants. Although an *environmental pathway* relating how changes in emissions would lead to changes in health effects is well established in qualitative terms, the quantitative relationships are uncertain.

A second type of health effect we consider is that resulting from exposure to a conventional air pollutant such as particulate matter that has a less uncertain effect on health than, say, the effect of mercury operating through fish consumption. Air pollution is of general interest across the country, but it also has a special relationship to the Great Lakes because control of conventional air pollutants can simultaneously lead to reduced emissions of hazardous air pollutants that are thought to contribute to contamination of sport fish. Conversely, we may find that policies designed to reduce emissions and contamination of sport fish lead to direct benefits that are difficult to quantify; but they may simultaneously produce indirect benefits such as reduced exposure to conventional air pollutants that can be quantified and valued with greater confidence.

FISH CONSUMPTION

The discovery of contaminated sport fish in the Great Lakes in the early 1970s prompted the health agencies in the Great Lakes States and in Canada to advise that individuals reduce or eliminate consumption of the most contaminated fish. Today all of the Great Lakes States issue consumption advisories for Great Lakes sport fish. Consumption advisories for sport fish are triggered by mercury and certain halogenated organic compounds such as polychlorinated biphenyls (PCBs), DDT and its metabolites (DDD and DDE), dieldrin, dioxins and chlordane. These chemicals are labeled *persistent toxic substances* because they do not biodegrade in the environment. Unless sequestered in sediment deposits or elsewhere, they remain available for biological uptake through different pathways of exposure, and they bioaccumulate at the top levels of the food chain, including in fish populations in the Great Lakes. Fish consumption has been identified as the major route of exposure to these chemicals. The weight of evidence clearly indicates populations continue to be exposed to persistent toxic substances in the Great Lakes basin and that health consequences are associated with these exposures. The health implications are summarized in Johnson et al. (1998).

The EPA has identified 15 pollutants that are of concern including pesticides, metal compounds, chlorinated organic compounds and nitrogen compounds. Most are bio-accumulative and persistent in the environment. Concentrations of these compounds are especially high in tissues of large, predatory species such as lake trout and salmon. Tissue concentrations of these compounds can range as high as 100,000 times concentrations in surrounding water. These concentrations can then be passed on to humans who eat the fish. Schantz et al. (1996) for instance found that individuals who consumed Great Lakes sport fish for more than 15 years had two to four times more pollutants in their blood serum than non-fish eaters. Jensen (1987) found that PCB's in blood serum increased with age and with the number of meals in which fish was consumed per year.

These pollutants are associated with deleterious effects on many target organs in humans and animals, including the liver, kidney, nervous system, endocrine system, reproductive organs and immunological system. Since humans do not metabolize these compounds easily, they are stored in body tissues. When a woman becomes pregnant they are readily transferred across the placenta to the developing fetus. In addition, as a result of consumption of contaminated fish, high levels of PCBs and DDT have occurred and been measured in the breast milk of some Great Lakes residents. Hence, children of exposed mothers are especially susceptible.

Some of these substances may be developmental toxicants. Subtle abnormalities (e.g., poorer motor reflex, impaired visual recognition) as well as lower birth weight and smaller head circumference have been reported in the children of women exposed to PCBs on the job (Taylor et al., 1989), DDT and mercury. These symptoms have also been reported in children of women who were regular consumers of Great Lake sport fish prior to and during pregnancies, compared to a nonexposed group (Fein et al., 1984; Jacobson et al., 1990). They are also confirmed by differences in the level of PCBs measured in umbilical cord blood.

A recent re-examination of children participating in one of the largest studies (Lake Michigan Maternal/Infant Cohort Study) found that the neurodevelopmental deficits observed in infancy persisted through age 11 (Jacobson and Jacobson, 1996) in the form of lower IQ scores, reading level, poorer memory, and attention span.

A small literature has also found effects of PCB in blood serum, and fish consumption rates on the immune system. Humphrey (1988) found that higher blood serum PCBs in pregnant women were associated with a greater rate of infectious illnesses in their infants and Tryphonas (1995) found a correlation between infection incidence and fish consumption in pregnancy.

Within the past several years, studies published in medical journals indicated a decline in the male sperm count and fertility over time, and shorter menstrual cycles associated with more frequent fish consumption (Mendola, et al., 1997). Also, studies have indicated a direct effect of reduced conception success as a result of larger Great Lakes fish consumption in male partners (Courval, et al., 1997). Some studies have identified certain chemicals--termed "endocrine disrupters"--as a culprit (Colborn et al., 1996), although this issue is highly contentious and EPA has convened a special panel to consider it. Exposure to certain chemicals prior to or during pregnancy may affect the development of the reproductive system of the fetus, leading to reproductive impairments later in life. Consequences of exposure thus occur in generations following the generation exposed to the chemicals.

Finally, several types of cancer have been associated with occupational exposure to PCBs, although causality has not been established. Several limited epidemiological studies have indicated a possible association of pesticide exposure with cancer. In discussing valuation of effects, we focus first on reproductive issues and then turn to cancer.

Valuation of Reproductive Effects

This section describes the capability of economics to value changes in health status of the type that have been described above. First we discuss affects on fertility, and second effects on child development. The section draws in part on Cannon et al. (1996).

<u>Fertility</u>

The benefits associated with a reduction in exposure to these chemicals depend on how the chemicals affect the reproductive process. The value placed on current fertility can be represented by the willingness to pay of potential parents for an increased probability of a successful pregnancy. Similarly, the value placed on future fertility can be estimated by the willingness to pay of parents for normal reproductive ability in their children.

Different techniques are required to estimate different willingness to pay values. Estimation of the willingness to pay to reduce the probability that one's children will experience reproductive difficulties is limited to stated-preference techniques. Estimation of the welfare change associated with a change in exposure to chemicals is best estimated through methods such as conjoint analysis or contingent valuation surveys that elicit information concerning how much individuals would be willing to pay to reduce the probability that their children would suffer from reproductive impairments. In the sense that the conditions are long term and have large perceived costs, such a survey might be similar to stated-preference methods used to determine willingness to pay to reduce the likelihood of low birth weight or birth defects.

When estimating the willingness to pay to reduce current reproductive impairment, information based on couples' actions in addition to stated responses may be utilized. One source of data is expenditures by infertile couples on infertility treatments that reflect the value that is placed on moving from a state of infertility to fertility. Infertility is defined as the inability to conceive after 12 months of intercourse without contraception. Using this definition, the rate of infertility for U.S. couples between the ages of 15 and 44 was about 7.9 percent or one couple in twelve in 1988.

There are few existing studies that have used stated preference techniques to directly estimate the benefits associated with a reduction in the health effects under consideration. Existing analyses of revealed preference have estimated willingness to pay for *in vitro* fertilization infertility treatments. Charges for a single episode of *in vitro* fertilization have been estimated to be roughly $8,000. (The literature has not examined willingness to pay for more common infertility treatment procedures, however.) Couples also expend effort on infertility treatments, composed of both money and any number of nonpecuniary items including the couple's time. The opportunity cost of the couple's time can be objectively estimated based on wage rates and time estimates. Other indirect costs such as physical discomfort and psychological stress are more difficult to quantify and may change over time as the couple progresses through the treatment.

Due to the uncertainty associated with the success of infertility treatments, the perceived benefits and costs of treatment are important in determining whether or not treatment will result in a net benefit to the couple. A couple that elects to begin infertility treatment is aware of the underlying common probability of success in the general population but not to themselves. Heterogeneous preferences for child-bearing result in different perceived benefits of treatment across couples. Although success rates vary by the treatment procedure, it is not likely that a treatment will be successful after the first episode and many couples undergo multiple episodes of infertility treatment.

One study made use of stated preference methods through a CV survey in which respondents were asked several different hypothetical questions related to IVF treatment (Neumann and Johannesson, 1994). On average, conditional on the knowledge that they were infertile, respondents were willing to pay $17,730 for IVF treatment having a 10 percent chance of success. Across all individuals and without knowledge of their fertility status, individuals were willing to make a one-time payment of $865 for insurance providing IVF if needed. The study also found that individuals would be willing to pay $32 per year in taxes for a public program giving 1,200 couples per year a 10 percent chance of successful fertilization.

In addition, survey respondents were asked to compare infertility risk reduction with mortality risk reduction by choosing between two uses of public funds: providing IVF coverage for state residents or reducing highway fatalities. The respondents identified a program resulting in 300 IVF babies as equivalent to one reducing auto deaths by 35 per year. This comparison illustrates one way of estimating an economic value without using dollar values.

Child and embryo development

While child development may be affected by exposure to the same pollutants that invite concern about infertility, substantial differences exist with regard to the factors determining the proper valuation methodology. For example, while many infertile couples desire a successful pregnancy, few are willing to obtain this goal irrespective of cost. A portion of infertile couples choose not to incur the costs of treatment and remain childless or choose an alternative such as adoption while others drop out of treatment before obtaining a successful outcome. It is not likely, however, that a couple having a child that is low birth weight or suffering from birth defects will choose not to provide the needed treatment for that child. One would expect that the demand curves for treatment of low birth weight and birth defects are much less sensitive to cost than the demand curves for infertility treatments.

The two types of effects also differ with regard to the question of whose welfare is relevant to the analysis. While infertility can be modeled in terms of the effect on the welfare of a *couple*, child development has an impact on the child and the parents and hence benefits are best framed in terms of the *family*. In addition to the obvious costs incurred by the child, medical costs, lost time and emotional distress are all costs borne by parents for at least a portion of the child's life. In some cases, costs may be borne by the parents after the child has reached adulthood.

Unfortunately the studies that are available to establish the benefits of reducing risks of these health effects have concentrated on the incidence of low birth weight and birth defects. Low birth weight (LBW) is defined as 2500 g or less, very low birth weight (VLBW) as 1500 g or less and extremely low birth weight (ELBW) as 1000 g or less. LBW is a major cause of neonatal and infant mortality in the U.S. Low birth weight survivors are more likely to have health problems than those born at a heavier birth weight. In addition, they are more likely to experience preschool developmental delays and additional adverse effects later in life (Chaikind and Corman, 1991).

The studies that have estimated the cost of low birth weight are limited to cost of illness analyses. One study estimated the incremental health care, education and child care cost of the 3.5 to 4 million children aged 0 to 15 born low birth weight (about 7 percent of all children in that age group) was between $5.5 and $6 billion (Lewit et al., 1995).

Table 1: Incremental Direct Costs of Low Birth Weight among Children from Birth to Age 15 in 1988

Age Group	Cost Type	Mean Cost per Low Birth Weight Child	Number of Low Birth Weight Children	Total Cost
Infancy	Health Care	$15,000	271,000	$4,000,000,000
1 to 2 years	All	not estimated	500,000	not estimated
3 to 5 years	Health Care	290	820,000	240,000,000
3 to 5 years	Child Care	180	820,000	150,000,000
6 to 10 years	Health Care	470	1,300,000	610,000,000
6 to 15 years	Special Education	150	2,400,000	360,000,000
11 to 15 years	Grade Repetition	45	1,100,000	50,000,000
Total			4,000,000	5,400,000,000

Source: Lewit et al. (1995)

Using similar methods, the cost of 17 major birth defects and cerebral palsy was estimated by another study to be $8 billion in 1992 (Waitzman et al., 1996). Cost estimates were based on direct medical and special service costs and indirect costs of increased mortality and morbidity. Medical costs included inpatient, outpatient and long-term care costs. Special services were comprised of developmental services such as day care centers and counseling and special education. Mortality and morbidity costs were represented by lost productivity. The total cost of a birth defect was defined as the discounted sum of all of the component incremental direct and indirect costs, assuming a 5 percent discount rate. As noted, however, these studies can only provide a lower bound estimate of the true costs associated with the incidence of these effects.

One other study examined the cost of mercury exposure by using estimates of the cost of compensating education and IQ loss (in terms of lower earnings and labor market participation), plus medical costs (Rowe, 1995). There are no studies that relate fetal mercury studies to IQ loss, although IQ deficits are likely to be associated with psychomotor retardation observed from mercury exposure. The study assumed a relationship between predicted psychomotor retardation and IQ loss, and calculated the present value costs at a 3 percent discount rate associated with IQ point loss. Finally it applied a willingness-to-pay to cost-of-illness ratio of 2 in order to reflect unmeasured aspects in calculating total damages form mercury. The central estimate per case was $289,000 (1992 dollars).

Valuation of Cancer Effects

As with other health effects, one can draw on several methods for valuation of reduced incidence of cancer. The traditional approach is to apply a willingness-to-pay estimate associated with accidental deaths to an estimate of the reduced annual deaths associated with a change in pollution exposure. But there are several problems that should be considered. First, there is a long latency period for cancer between exposure to potential carcinogens and the manifestation of disease and deaths. If people value current health more than future health, this suggests that the willingness-to-pay estimates from accidental death studies should be revised down for cancer fatalities. A related concern is that older people with fewer years of life expectancy are primarily the people affected by cancer (about 70 percent of cancer mortality occurs in individuals over 65 years of age). Studies of the willingness to pay to avoid accidental death at work and elsewhere apply to individuals who average about 40 years old. Several studies indicate that the value of a statistical life fall somewhat for older individuals.

On the other hand, work by psychologists on risk rankings suggests that people might be more willing to pay to avoid death from a "dreaded" disease, like cancer, than one involving a more familiar cause (like auto accidents). In addition, we are here abstracting from the willingness to pay to avoid the morbidity associated with cancer, which can be treated as a separate issue.

To value morbidity associated with cancer researchers have relied primarily on cost-of-illness approaches. Hartunian (1981) estimated average direct costs per cancer patient to be $49,000, including medical and administrative costs. Indirect costs including change in earnings and the provision of household services associated with nonfatal cancers was estimated by Rowe (1995) to be $87,000. The total cost of illness for nonfatal cancers is the sum, or approximately $136,000. Rowe (1995) amends this by applying a willingness-to-pay to cost-of-illness ratio of 1.5 resulting in an estimate of $204,000 per case. Other approaches are possible, however. For example, in principle, the conjoint analyses discussed above could be used to obtain the willingness to pay to avoid a statistical case of cancer.

AIR PATHWAYS

Valuation of health effects associated with air pollution is somewhat more straight forward than valuation of those associated with fish consumption. In addition to uncertainties that apply to air pollutants, the prediction of changes in health effects with respect to fish consumption is complicated by the role of the aquatic ecological system. Also, health effects from air pollution are thought to be more prominent, have been more widely studied and are better understood.

To illustrate valuation of health effects from air pollutants we focus on the suspected effects of particulate matter, which is one of six so-called "criteria" air pollutants regulated primarily for their effects on health under the Clean Air Act and its Amendments. The EPA has authored Criteria Documents for each pollutant that contain thousands of pages evaluating toxicological, clinical, and epidemiological studies that relate particular criteria pollutants to a variety of health endpoints.

Mortality Effects

There exists strong evidence of premature mortality associated with exposure to particulate air pollution, but there continues to be significant controversy over its precise measure. Concentration-response functions can be drawn from the literature that estimate the change in risk of premature mortality that results from a small change in particulate concentrations, though one can have much more confidence in the efficacy of these functions with respect to small changes than for large changes.

The most common approach to valuation is to apply a value of a statistical life to the change in the number of statistical deaths predicted to result from a change in particulate concentrations. A key choice is the value to apply. Estimates drawn from labor market studies yield values ranging from $1 million - to $9 million, the upper end exceeding values drawn from contingent valuation studies of accidental death risks. Contingent valuation studies may be somewhat more appropriate for valuing mortality risks in the environmental health context. One example is the Jones-Lee study (1985) that asked about willingness-to-pay for riding with a bus company with a better safety record than another bus company. The results identified that an adjustment that would lower the *value of a statistical life* is appropriate for individuals in older age groups, who are the primary subjects of premature mortality resulting from particulates. They show a declining ratio of willingness to pay with age for 70 year olds to 40 year olds of about 80 percent. Moore and Viscusi (1988) show a steeper decline in willingness-to-pay, with the ratio of 70 to 40 year olds being about 40 percent. Accounting for these considerations in a recent examination focused specifically on particulates, Burtraw, Krupnick et al. (1997) used a probability distribution to indicate the range of possible values, with a mean of $3.1 million.

In the recent Regulatory Impact Analysis (RIA) for Ozone and Particulate National Ambient Air Quality Standards (1997), the EPA used a value of $4.8 million ($1990) for the "high" value of a statistical life applied to deaths related to particulate exposure. However, they have also identified an adjustment to account for the age of the affected population and other problems with the underlying basis of the $4.8 million figure, suggesting a "low" value of $2 million might be more appropriate. EPA's RIA used a discounted life-year approach, working with the estimate of $2 million per statistical life to derive a value of a life-year of $120,000.

The obvious mismatch between accidental deaths and deaths from cancer or particulate exposures has raised serious concerns about the appropriateness of using the traditional valuation techniques (Krupnick et al., 1998; Thurston et al., 1997). The research frontier involves expressing excess deaths in terms of changes in life expectancy and using survey research to estimate the WTP today of people to increase their life expectancy (mostly from risk reductions late in life). One controversial study has estimated that the WTP today for a "treatment" increasing life expectancy by one year beginning at age 75 (where life expectancy is 10 years normally, but would be extended in this scenario to 11 years), is about $1,500 over the adult population in Sweden. According to Johannesson and Johansson (1997) and for their particular case only, this implies a value of statistical life of $70,000-$130,000. Until this literature matures, the preferable approach is to treat these values as probability distributions and to explore the sensitivity of results to alternative values in these distributions.

Morbidity Effects

Dozens of morbidity effects have been identified with particulate pollution, including acute and chronic cardiopulmonary and respiratory effects, and prevalence of chronic illness. Health endpoints that can be valued separately include changes in chronic bronchitis risk, respiratory hospital admissions, emergency room visits, asthma attacks, restricted activity days and many others. To apply values to these endpoints is conceptually simple. Unit values for various endpoints are drawn from the literature and multiplied by the expected change in the incidence of that effect.

Willingness-to-pay (as opposed to cost-of-illness) estimates are available for only about half of identified endpoints. Also, these estimates characteristically have relied on small sample sizes, there is limited variation in the health effect studied, and few studies that have tried to replicate previous results. However, they have been widely reviewed, there is some consistency across outcomes, and these reviews provide accessible interpretations of the results. Where the willingness-to-pay studies prove weak, valuation must rely on cost-of-illness. A summary of values used for a few illustrative endpoints are provided in Table 2.

Equity Considerations in Economic Valuation

A crucial step in valuation is the aggregation from measures of individual willingness-to-pay to a measure for society. In the most common applications, individuals are treated anonymously. No person's welfare is weighted more heavily than anyone else's, and health effects that are valued are treated consistently without regard to an individual's income or social status. Hence, in this sense valuation methods are very equitable and most people find this a desirable feature.

Adjusting for quality of life and life expectancy

However, there are some applications where equity considerations might suggest that differences among individuals should matter in valuation. In particular the age and prior health status of individuals are factors that decision-makers might want to consider in accounting for the benefits of reduced pollution. These factors are relevant for efficiency as much as for equity.

Age at time of an incidence of disease (and sex, due to differing life expectancy) is an important equity consideration. The earlier example of triage is a case where a preference for allocating resources toward saving relatively younger lives is readily apparent. Age is also the one factor that distinguishes individuals in the WHO study described previously. Diseases affecting different age groups were viewed differently by the health professionals in the study. A disease that struck a 23 year old would be viewed differently than a disease that struck a 65 year old for two reasons. First, a higher number of healthy life years would be lost in the

Table 2: A Sampling of Values Used in Health Benefits Valuation

Endpoint	Monetary Value	Original Study or Source	Referenced in
Cardiac hospital admission	in 1992 $ 14,000		Chestnut (1995)
Respiratory hospital admission	in 1989 $ 6,306	Krupnick and Cropper (1989)	Lee et al. (1995)
Restricted activity day	in 1990 $ 51.38	Krupnick and Kopp (1989)	Lee et al. (1995)
Adult chronic bronchitis	in 1989 $ 210,000	Viscusi et al. (1991) Krupnick and Cropper (1992)	Lee et al. (1995)
Acute cough	in 1990 $ 1.26 (33%) 7 (34%) 13.84 (33%)	Dickie et al. (1987) Tolley et al. (1986) Loehman et al. (1979)	EPA (1996)
Phlegm day	in 1990 $ 3.77 (33%) 10 (34%) 36.44 (33%)	Dickie et al. (1987) Tolley et al. (1986)	EPA (1996)
Eye irritation day	in 1990 $ 15.72 (33%) 15.72 (34%) 34.88 (33%)	Tolley et al. (1986)	EPA (1996)
Child chronic bronchitis	in 1989 $ 132	Krupnick and Cropper (1989)	Lee et al. (1995)
Minor respiratory-related restricted activity day	in 1990 $ 22 (central estimate)	Krupnick and Kopp (1989)	Chestnut (1995)
Respiratory restricted activity day	in 1990 $ 45 (central estimate)	Harrison and Nichols (1990)	NERA (1993)
Asthma attack	in 1990 $ 31 (central estimate)	Rowe and Chestnut (1985)	EPA (1996)

Source: Bloyd et al.

former case, and second many of those years are viewed as especially precious in part because of responsibilities in child-rearing. The study coupled the relative ranking about the relative severity of disease described previously with information about the number of healthy years that would be lost due to the disease to arrive at the information in the **insert box**. Comparing a healthy 23 year old with a 65 year old who already has an impaired health status and shortened life-expectancy would make these considerations even more poignant.

These equity considerations are not particular to the exercise of monetary valuation, or even to the consideration of environmentally related exposure. Even if one stops short of valuation and restricts oneself to comparisons among types of health effects in order to prioritize the use of resources, as did the WHO study, one can not escape a consideration of the equity issues.

Involuntary exposures

To assess the possible tradeoffs in environmental protection, decision-makers also need information about the manner in which individuals are affected because many feel involuntary exposures should be considered differently from voluntary ones. For example, the decision whether to wear a seat belt or to smoke cigarettes is perceived as an individual decision. However, inadvertent exposure to reckless drivers or second-hand cigarette smoke is a different matter, in the minds of many individuals, because risks are imposed on third-parties without their consent and therefore should be given greater weight than risks that are accepted voluntarily. Though environmental exposures can be of either kind, often they are involuntary.

Effects on sensitive populations

Important equity considerations also emerge from the knowledge of who specifically will suffer a change in health status as a result of pollution. An example from economic philosophy illuminates this distinction. Imagine yourself in a room of 1,000 persons and you are informed that with equal probability one of you will suffer a severe disease unless the group acts to prevent it. Imagine that the moderator has an envelope in his hand with the name of the affected individual. Presumably everyone in the room would report a positive willingness-to-pay to prevent this disease.

Now imagine that the moderator opens the envelope and identifies the individual before eliciting the willingness-to-pay to prevent this disease. Assuredly, the outcome would be different. The affected individual would be willing to pay substantially more while others would have no selfish incentive to pay to prevent the disease. However, others would have an altruistic motive to prevent the disease that was lacking in the first scenario. By analogy, if a sub-population is particularly sensitive to exposure from an environmental contaminant (whether because of some inherent trait or through circumstance beyond their control), the economic measure of society's willingness-to-pay may be larger. This could be attributable to the existence of an altruistic motive that adds to the economic efficiency measure of willingness to pay for statistical events.

For example, in the decision to consume sport fish from an area with a fish advisory recommending against consumption of fish caught there is to some degree a voluntary risk-taking, which works against making special equity considerations. However, many would view consumption of contaminated fish by some populations to be an involuntary form of exposure, due to social and economic factors that limit the options that these individuals have available. Native American and lower income populations often have diets that include unusually high levels fish consumption, and so special economic considerations emerge for public policy. Similar considerations apply to policies to regulate air pollution, where sub-populations have been identified to be particularly susceptible. When specific sub-populations can be identified to be at special risk, then an altruistic motive may emerge for addressing environmental problems.

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